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Fuel and Cost Optimization of Grid-Connected MTG-PV-Based Hybrid System

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An MTG-PV hybrid system is a reliable DG-based system because PV is unpredictable non-traditional energy source whereas Mictroturbine is a controllable traditional energy source, which will cancel out each other's drawbacks. In this paper, a microturbine generation system (MTG) is considered as the backup generation to meet the energy requirements when solar energy is not sufficient. Main objective of this paper is optimization of Fuel and Cost of grid-connected MTG-PV hybrid system. Analysis of power management and fuel optimization is carried out using the MATLAB/SIMULINK platform. HOMER (Hybrid Optimization Models for Energy Resources) power optimization software by NREL (National Renewable Energy Laboratory) is used to optimize the cost of the hybrid system.

Keywords: *Microturbine generation (MTG), Distributed generation (DG), HOMER, Cost of energy (COE), Net present cost (NPC).*

1.0 INTRODUCTION

DG-based technologies such as solar energy one clean, inexhaustible, unlimited and environmental -friendly. Such characteristics have attracted the energy sector to use renewable energy sources on a larger scale. However, all renewable energy sources have drawbacks. PV and Wind sources are dependent on unpredictable factors such as weather and climatic conditions. DG includes both renewable and traditional energy sources. The combination of these two, i.e. one traditional and one renewable energy source, will make a hybrid system which may cancel out each other's drawbacks. The DG based on microturbine technology is new and a fast growing business, which is controllable. By using it as a backup generation source, we can solve the problem of power management.

Although a hybrid plant may use other combinations of energy sources, the combination of PV and MTG systems are particularly complimentary. Photo voltaic generation is high on capital cost and low on operational cost; once installed, there is no ongoing fuel costs and the maintenance cost is also very low. On the other hand, microturbine generation is low on capital cost and high on operational cost compared to PV due to its need for fuel and maintenance. This combination is also environmentally friendly in that the emission of greenhouse gases from the microturbine is very low compared to the conventional fossil fuel steam turbines. In this paper, analysis of Power management and Fuel optimization is done using MATLAB software. The Hybrid Optimization Model for Electrical Renewables (HOMER) software is used as a tool to carry out the research based on cost optimization. The main objective of this paper is to assess the feasibility and economic

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viability of utilizing hybrid MTG-PV-based grid connected power supply systems to meet the load requirements.

2.0 MTG SYSTEM

Now-a-days, the DG system based on microturbine technology is becoming more popular with a range of power generation between 25 kW and 500 kW. Major advantages of microturbines are few moving parts; compact systems; good; efficiency in coregeneration; low emissions; can utilize a variety of fuels (including waste fuels); low investment costs; low maintenance costs; controllable DG source; small size; high operating efficiency; can be operated with grid and in standalone mode. Disadvantages found in microturbines are low fuel-to-electricity efficiencies; reduced power output and efficiency with higher ambient temperatures [2]. Applications of MTG system include as base load; peak saving and standalone power; in CHP system; UPS and standby services. Microturbine efficiency for unrecuperated configuration is 15 %, for recuperated is 20–30 % (in our case) and that with Heat Recovery is up to 85 %. MTG system with back-to-back converter interface as shown in Figure 1 is used. Detailed modeling of this system is done using the references [1–4].

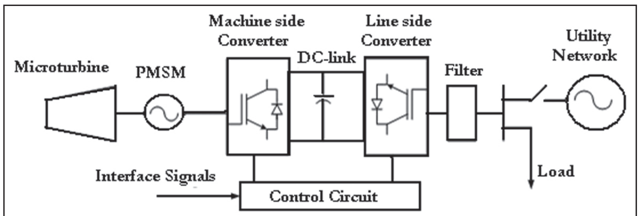


FIG. 1 MTG SYSTEM WITH BACK TO BACK CONVERTER INTERFACE [1]

3.0 PV SYSTEM

PV technology is one of the most popular renewable energy-based technologies with rang of power generation between 1 kW and 50 kW. The word photovoltaic comes from "photo", meaning light, and "voltaic", which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight". Photovoltaic is often referred to as PV. Major advantages of PV are they are safe, clean and quiet to operate; they are highly reliable; they require virtually no maintenance; they operate cost-effectively in remote areas and for many residential and commercial applications. disadvantages found in PV are unpredictable output; high capital cost, since solar is minimally subsidized compared to polluting energy technologies, the initial cost of solar seems a bit high when compared directly. Its conversion efficiency is around 12.8 %.

The block diagram of a PV grid-connected system is shown in Figure 2. The main objective from this interfacing is to feed all the collected energy at the PV plant to the load and remaining power into grid. Here two-stage grid-connected PV system is used in this hybrid system. The modeling of PV system consist of mainly of five parts: the PV array, MPPT controller, Boost converter, Line side converter controller and LCL filter. Detailed modeling of this PV system is done using the references [5–8].

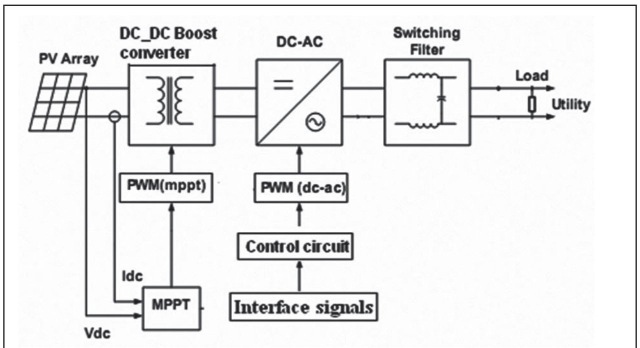


FIG. 2 GRID-CONNECTED TWO-STAGE PV SYSTEM

4.0 HYBRID MTG-PV SYSTEM

A typical MTG-PV hybrid generation system, consisting of a 45 kW PV and a 45 kW MTG system along with its power electronics interface, is presented in this section. There are many ways to integrate different DG sources to form a hybrid system. The methods can be generally classified into three categories: DC-coupled, AC-coupled and hybrid-coupled. The AC-coupled scheme can further be classified into power frequency AC (PFAC)-coupled and high-frequency AC (HFAC)-coupled systems [9]. Hybrid systems can be broadly classified series hybrid, switched hybrid and parallel hybrid configurations. Figure 3 shows the block diagram of the proposed parallel connected (PFAC-Coupled) hybrid system.

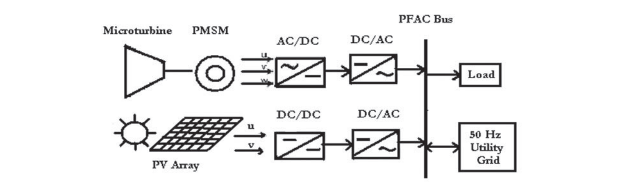


FIG. 3 SCHEMATIC DIAGRAM OF PARALLEL CONNECTED MTG-PV HYBRID SYSTEM

5.0 ANALYSIS METHOD

5.1 MATLAB Software

In this paper, using the MATLAB/SIMULINK platform, Power management and Fuel optimization of a hybrid MTG-PV system is presented.

The flowchart, as shown in Figure 4, is used to calculate the load share of the each generator. According to that if the load demand is less than PV system, then PV system will supplied the entire load and remaining power generated from the PV is supply to the grid. MTG system runs on no load and use minimum amount of fuel at that time. But if load demand is beyond the PV capacity, then MTG system supplies the remaining load demand, if that required power from the MTG system is more than minimum MTG system capacity, i.e 15 kW here, because for the load demand less than 15 kW, the efficiency of MTG system becomes very poor. Hence it is not optimum solution to run MTG system at such load demand. In that situation, the solution is to take required power from the grid. If load demand is beyond the capacity of both MTG-PV system, then remaining power is taken from the grid. This way MTG system works as a back-up generation and hence power management, fuel optimization and reliable operation of the system are possible.

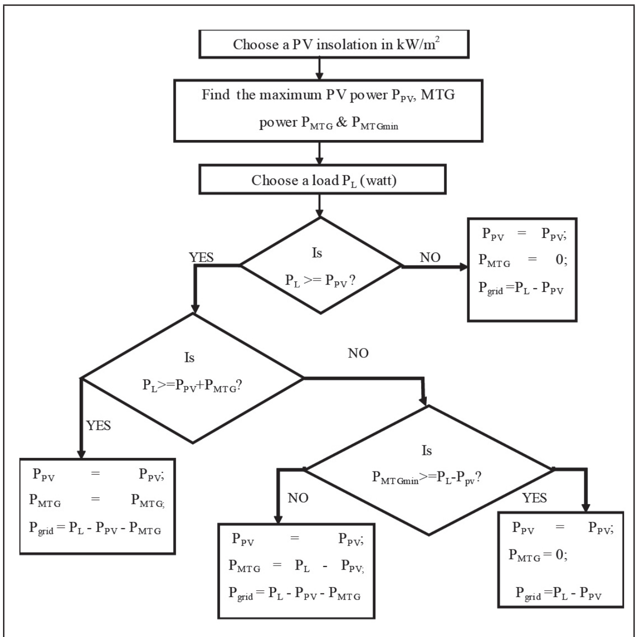


FIG. 4 FLOWCHART TO DETERMINE THE POWER SHARE OF THE GENERATORS

5.2 HOMER Software

HOMER version 2.81 [10–12] has been used in this study to investigate the feasibility and cost analysis comparisons of various DG sources. The HOMER (Hybrid Optimization Models for Energy Resources) is a micropower optimization software developed by Mistaya Engineering, Canada, for the National Renewable Energy Laboratory (NREL) USA, since 1993, which can be useful for evaluating designs by simplifying the given task for both off-grid and grid-connected power systems for many of the applications.

There are three main tasks that can be performed by HOMER: simulation, optimization and sensitivity analysis. In the simulation process, HOMER models a system and determines its technical feasibility and life cycle. In the optimization process, HOMER performs simulation on different system configurations to come out with the optimal selection. In the sensitivity analysis process, HOMER performs multiple optimizations under a range of inputs to account for uncertainty in the model inputs [10–12].

Inputs to HOMER contain load data, renewable source data, system component specifications and costs, and various information regarding optimization. In this paper, Net Present Cost (NPC) and Cost of Energy (COE) have been considered as performance metrics to evaluate and compare the performances of different systems. The COE is a more trustworthy number than the NPC, therefore in this analysis COE has counted as the primary metrics [10–12].

6.0 SIMULATION

6.1 MATLAB Simulation

6.1.1 Design Specifications

TABLE 1	
LIST OF PARAMETERS USED IN MTG AND PV SYSTEM	
The Speed governor parameters	Gain (k) = 25, T1= 0.4, T2=0.0005, Z=1.
Parameter of PMSM:	Rs = 0.7 Ω,
	No. of poles=2,
	Ld= Lq= 0.6875 mH,
	λ = 0.0534 wb,
	F = 0.001 Nms
	J = 0.0008 kgm^2
	Maximum power output = 45 kW
Photovoltaic array:	No. of series modules in string Nsa = 32; No. of parallel modules in string Npa=25; Output voltage rating = 540 V; Output current rating = 87.5 A; Maximum power output = 47250 w (for insolation level = 1 Kw/m^2)
Boost converter:	C1=1000 μF , L= 0.5 mH, C2= 1000 μF
Grid parameter:	R =0.4 Ω, L=2 mH, 480 V, 50 Hz
LCL filter :	L1 = 6.5 mH, L2= 1 mH, C = 3.5 kVAr
Load :	30, 50, 70 and 120 kW

System Configuration

Simulink/MATLAB model of Hybrid MTG-PV-based grid-connected system is shown in Figure 5. Where, models of MTG and PV shown in Figures 1 and 2, respectively, are connected in parallel with PFAC-coupled bus. For the different load and same insolation level, this hybrid system is run in MATLAB.

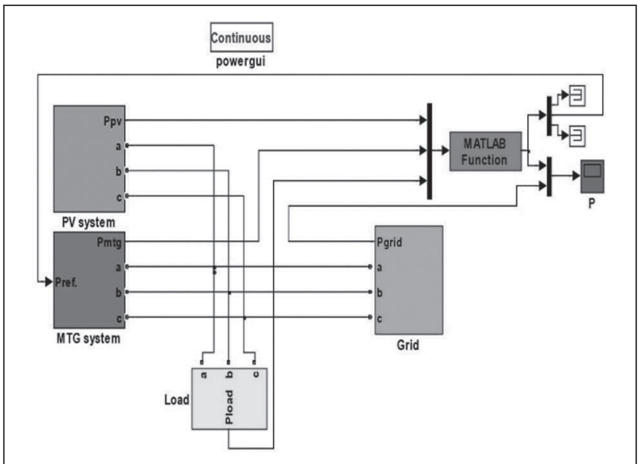


FIG. 5 MATLAB/ SIMULINK MODEL OF HYBRID MTG-PV-BASED GRID-CONNECTED SYSTEM

6.2 HOMER Simulation

6.2.1 Design Specifications

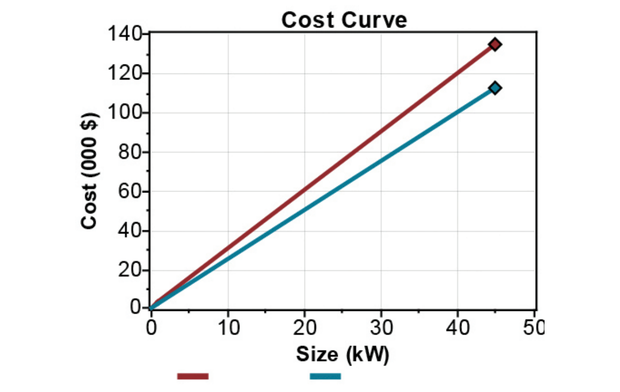
In a hybrid MTG-PV energy system, there are five main components to be considered. They are PV, Microturbine, converter, Load and Grid. In order to meet the user AC load profile, the following design specifications for each of the component are provided. A brief summary on the data for each of the selected components in the system is provided in this section. Table 2 gives the cost of different systems components in this hybrid system.

TABLE 2

COST OF DIFFERENT SYSTEM COMPONENTS

System Components	Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
PV	1	3,000	2,500	0
Microturbine	1	1,000	800	0.005
Converter	1	250	250	20

(a) *PV*: It should be highlighted that this PV array would only generate electricity at day time, from 6 am. to 6 pm. At night, there is no electricity generated from PV. Therefore, the output from solar would be 0 W [12]. At night, either battery or generators (here microturbine) will take over the task. For economical analysis, it is assumed that per kW of PV module would cost. ₹ 1,50,000. The cost of replacement is assumed to be ₹ 75,000. Operating and maintenance costs one assumed to be zero since it is negligibly small. Solar system equipment prices are taken from reference [13]. Cost curve of PV is as shown in Figure 6.



Sizes to consider: 45 kW
Lifetime: 50 yrs
Slope: 20°

FIG. 6 COST CURVE OF PV

Solar irradiations: The solar resource data for Gujarat is obtained from NASA surface meteorology and solar website [14]. Latitude and Longitude for Gujarat state are given below. It is taken for the Surat city in Gujarat to check the feasibility of this hybrid system over there.

Latitude: 21° 17″ North

Longitude: 72° 59″ East

Time zone: GMT + 5:30 (India)

Gujarat has very high potential of solar energy with an annual average irradiation of 5.52 kWh/m²/d. Figure 7 shows the average monthly solar radiation and clearness factor,

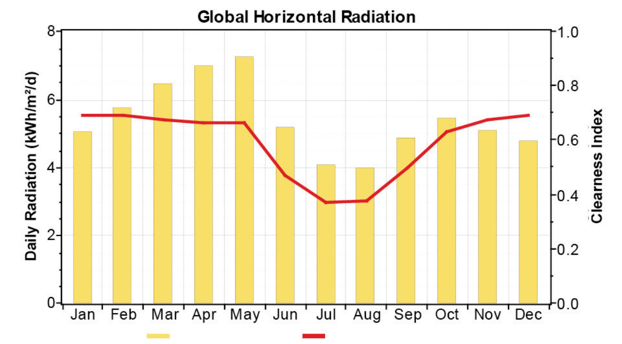


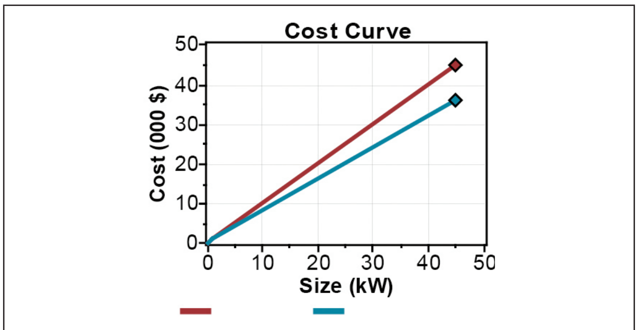
FIG. 7 MONTHLY SOLAR RADIATION WITH CLEARNESS INDEX

which clearly shows the months with the highest solar radiation are March through May.

The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions [16].

6.2 AC Generator

Microturbine is mainly used as a backup generator. It has Low installed capacity, high shaft efficiency. Figures 8 and 9 show the cost curve and efficiency curve of microturbine, respectively. The microturbine mainly



Sizes to consider: 45 kW
Lifetime: 50,000 hrs
Fuel used: Natural gas
Price: $ 0.1/m³

FIG. 8 COST CURVE

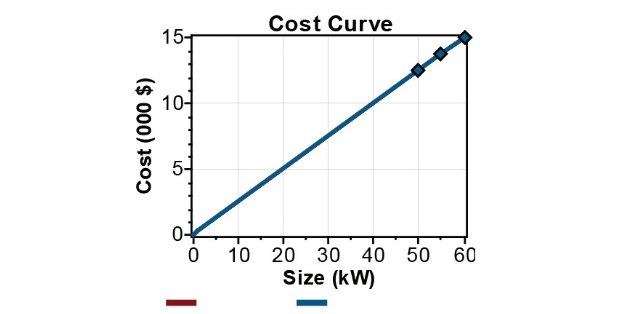
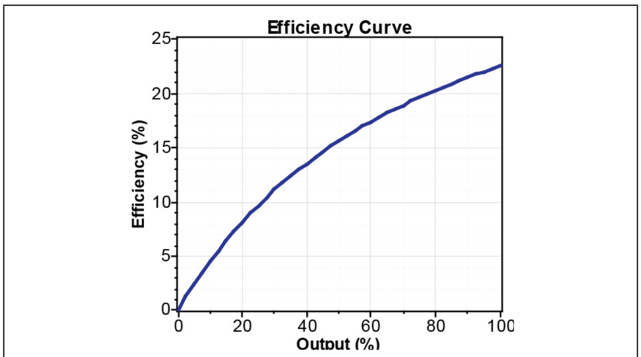


FIG. 9 EFFICIENCY CURVE

operates at night since solar power is not available at this time, and the load demand is higher at night. In the day time, microturbine would operate if the solar power could not meet the load demand. The initial cost and the replacement cost of 1 kW microturbine is assumed to be ₹ 50,000 and ₹ 40000, respectively. For operating and maintenance cost, it is assumed to be 0.25 ₹/yr. This is because the area considered is a remote area. Therefore, difficulty arises in transportation problem when maintenance is required, which would indirectly add up the cost. Microturbine system equipment prices are taken from reference [15].

6.3 Converter

A converter is required to convert AC-DC or DC-AC [17]. The inverter is rated based on the selected PV array. Since 45 kW output would be generated from PV, the inverter is rated at 50 kW to fully supply the power from PV. However, it is assumed that the inverter and rectifier have an efficiency of 90 % and 85 %, respectively [12]. Therefore, the supplied power would be nearly about 45 kW. The initial cost of the inverter is assumed to be 7500 ₹/kW, which is the same as the replacement cost. There is 1000 ₹/kW operating and maintenance cost estimated. Figure 10 shows the cost curve of the converter.



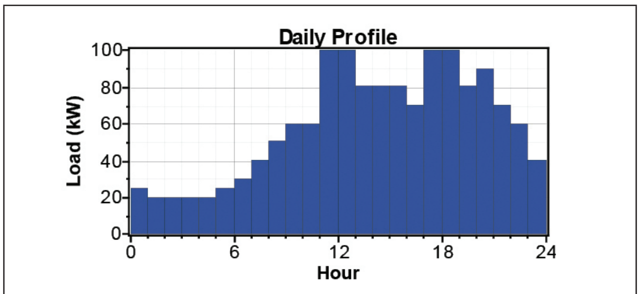
Sizes to consider: 50 kW
Lifetime: 20 year

FIG. 10 COST CURVE OF CONVERTER

6.4 AC Load

Primary Load The load profile is based on a hypothetical building as shown in Figure 11. Figure 12 shows the seasonal load profile. The load profile has a major peak at 12 noon to 2 pm. and 6 to 8 pm.

Load profile



Scaled annual average: 1,000 kWh.
Scaled peak load: 102 kW.

FIG. 11 DAILY LOAD PROFILE

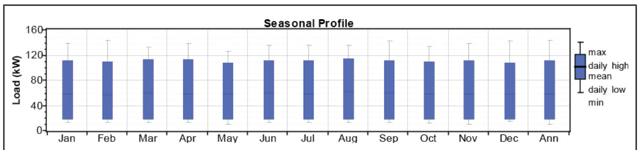


FIG. 12 MONTHLY LOAD PROFILE

6.5 Grid

This proposed system is a grid-connected system in which the Grid acts as a backup power component. The grid is activated and supplies electricity when there is not enough renewable energy power to meet the load from the hybrid system [17]. Different rate of grid are given in Table 3.

TABLE 3				
DIFFERENT RATE OF GRID				
Rate	**Power price $/kWh**	**Sell-back rate $/kWh**	**Demand rate $/kW/mo**	**Applicable**
Rate 1	0.035	0.08	0	Jan–Dec All week 00:00–24:00

System Configuration

The configuration of the hybrid MTG-PV system is shown in Figure 13. The PV is used as the base load supply which produced DC power. It is then converted into AC source by using an inverter [12]. MTG is used as a backup generator which produces AC power. The system is composed of 45 kW PV system, 45 kW MTG and a grid-connected inverter of 50 kW capacity. The system is designed to have a life time of 20 years, so the PV panels will not be replaced.

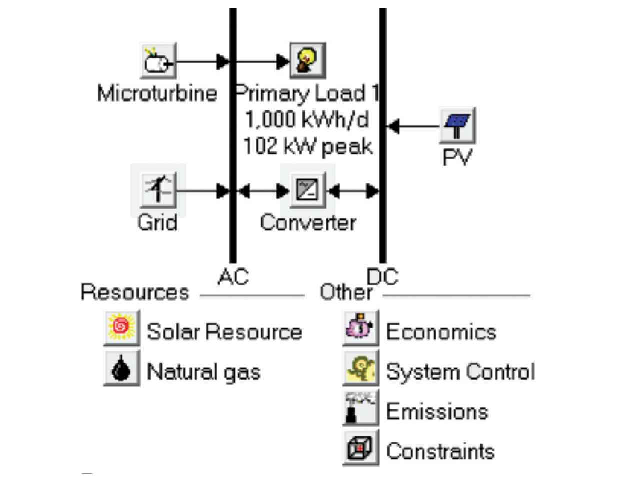


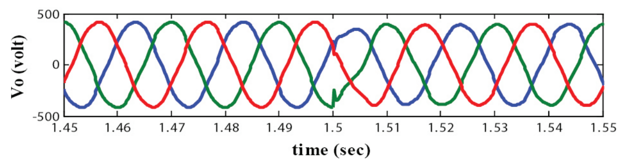
FIG. 13 CONFIGURATION OF HYBRID MTG-PV SYSTEM IN THE HOMER

7.0 RESULTS AND ANALYSIS

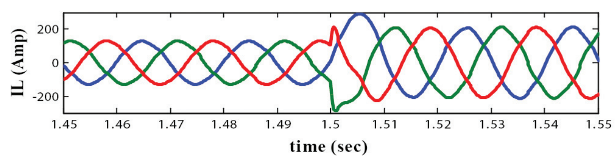
7.1 MATLAB Simulation Results for Grid-Connected Hybrid System

7.2 Optimization of MATLAB Simulation Results

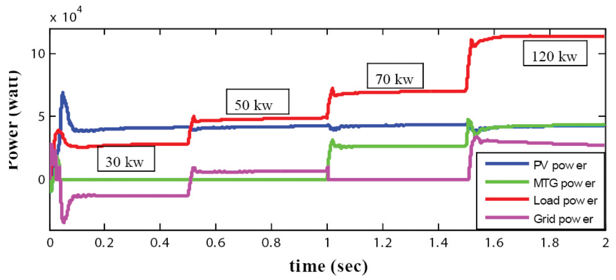
Results of MATLAB simulation with different load are as shown in Figure 14. Figure 14 (c) shows comparison between different power variations under different load conditions. In this case, insolation level is taken constant 1 kW/m^2 during the whole process. Hence, PV is able to give its maximum power output, i.e. 45 kW, during the whole process. Whenever the load demand is less than PV capacity, PV will supply the load and remaining power is given back to the grid, whereas MTG system runs at its minimum fuel demand. At time t = 0.5, load demand is higher than PV capacity but remaining required load demand from MTG system is less than minimum capacity of MTG system, hence it is not an economical solution to start MTG system, as the efficiency of MTG system is very poor during that period (See Figure 9). So, take that power from the grid. (See Figure 14 (c), for t = 0.5–1 sec). During the time t=1–1.5 sec, MTG system, supplies the remaining required power of the load, as required demand from



(a) ENLARGED VIEW OF LOAD END SIDE VOLTAGE VARIATION



(b) ENLARGED VIEW OF LOAD END SIDE CURRENT VARIATION



(c) COMPARISON BETWEEN DIFFERENT POWER VARIATION

FIG. 14 SIMULATION RESULTS OF MTG-PV HYBRID SYSTEM WITH DIFFERENT LOAD USING MATLAB/SIMULINK MODEL

MTG system is higher than minimum capacity of the MTG system. At last, during time t=1.5–2 sec, load demand is beyond the capacity of combine MTG-PV capacity. Hence, both MTG and PV supply its maximum power output, and remaining power is taken from grid. This way MTG system works as a back-up generator during time t=1–2 sec. This way bidirectional power flow is possible and even very good power management and fuel optimization are achieved through it.

7.2 HOMER Simulation Results for Grid Connected Hybrid System

7.3.1 Cost Summary

Detailed cost summary of different components of hybrid system with respect to different types of cost is shown in Figure 15. According to that, PV has the highest capital cost, whereas almost negligible O and M cost compare to other system. Similarly, microturbine has the highest fuel cost and replacement cost, whereas less capital cost compare to PV. Grid has higher operating cost.

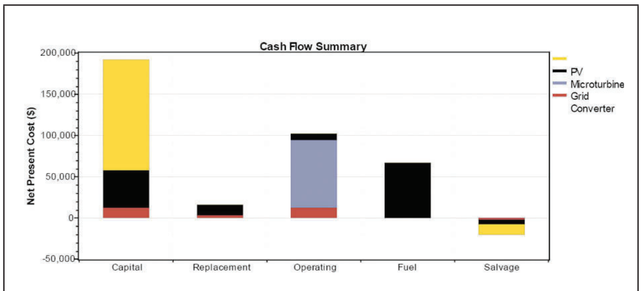


FIG. 15 DETAILED COST SUMMARY OF DIFFERENT COMPONENTS OF HYBRID SYSTEM ACCORDING TO DIFFERENT COST TYPE

7.3.2 Electrical Production

As shown in Table 4, the renewable energy (PV) fraction is 21 % of the total energy produced. Microturbine fraction is 30 %, whereas remaining power is taken from the grid, hence grid fraction is remaining 49 % of the total energy production. This way power management is possible using HOMER software. According to Tables 4 and 5, from the total energy production of 3,72,842 kWh/yr, 3,65,000 kWh/yr energy is consumed by the load.

TABLE 4

ELECTRICAL SIMULATION DATA

Component	Production (kWh/yr)	Fraction
PV array	78,404	21 %
Microturbine	113,007	30 %
Grid purchases	181,431	49 %
Total	372,842	100 %

TABLE 5

ELECTRICAL SIMULATION DATA

Load	Consumption (kWh/yr)	Fraction
AC primary load	365,000	100 %
Total	365,000	100 %

Figure 16 shows graph of the monthly average electrical production for hybrid MTG-PV system connected with grid.

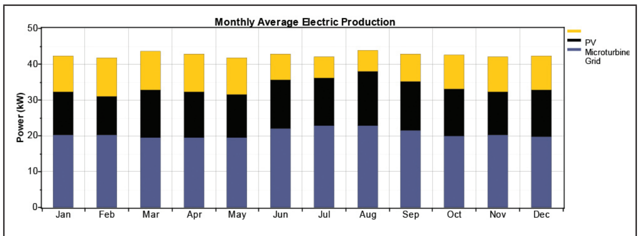


FIG. 16 MONTHLY AVERAGE ELECTRIC PRODUCTION FOR HYBRID MTG-PV SYSTEM CONNECTED WITH GRID

7.3.3 Comparison of cost

We consider three different system i.e. Grid-connected PV system, MTG system, MTG-PV hybrid power system. After comparing these three different systems individually with the same data, the cost comparison is achieved as shown in Table 6.

TABLE 6				
COMPARISON OF COSTS				
System	**Initial capital cost ($)**	**O&M ($/yr)**	**Total NPC ($)**	**Cost of energy (COE) ($)/ kWh**
PV	1,46,250	3050	1,85,241	0.092
MTG	45,000	32,883	4,65,354	0.1
MTG-PV	1,92,500	12,847	3,56,725	0.076

7.4 Optimization of HOMER Simulation Results

After analyzing HOMER simulation results, it can be suggested that the Grid-connected Hybrid MTG-PV system is most suitable compared to the other configuration and also the system is most suitable for Gujarat location. Also, the comparison of different systems for total Net Present Cost (NPC), Initial capital cost, operating cost and Cost of Energy (COE) for such a system for one year is as shown in Table 6. The COE of Hybrid MTG-PV system is very less compared to individual PV and MTG system. Also, COE of Hybrid system is 0.076 $/kWh i.e. 3.8 ₹/kWh, which is very less compared to electricity, price with conventional energy sources i.e. of around 4.5 ₹/kWh in Gujarat. Also, this combination is environmentally-friendly in that the emission of greenhouse gases from the microturbine is very low compared to the conventional fossil fuel steam turbine, hence this hybrid system is very promising for a long-term policy.

8.0 CONCLUSION

The analysis on hybrid system suggests the role of the hybrid system as a reliable energy source and the suitability of developed model for power management studies of hybrid distributed generation systems. In this paper, the ability of the PV in picking up the load whenever sufficient insolation is available and the ability of the MTG system (working as a backup generator) in meeting the load demand whenever there is not sufficient insolation, are presented. Also the results of MATLAB simulation show that Fuel optimization achieved with this hybrid model is very well.

The results of HOMER modeling show the cost summary, electrical production and cost of MTG-PV hybrid system. Experimental results of HOMER software show that the COE of the grid connected Hybrid MTG-PV system is 3.8 ₹/kWh, which is very less compared to electricity price with conventional energy sources, i.e. of around 4.5 ₹/kWh in Gujarat, i.e. power generation from this hybrid system is cheaper than that from conventional energy sources. Also the comparison of cost shows that COE of hybrid MTG-PV system is less compare to that of individual grid-connected PV and MTG system. So it is economical to use Hybrid system instead of individual PV and MTG system. NPC-wise, this Hybrid system is better than MTG system.

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